

Forward and Reverse Logistics Network Design with Sustainability for New and Refurbished Products in E-commerce

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ABSTRACT

There has been an enormous growth in the availability of refurbished goods in the online marketplace. These days, consumers can buy either the new products or refurbished products based on their budget and individual preferences. As a result, e-commerce firms need to redesign their existing forward and reverse logistics networks while focusing on supply chain sustainability. This paper proposes a novel forward and reverse logistics network design (FRLND) along with a consumer pickup and demand facility within the promised time window while addressing the complexities related to e-commerce platforms, suppliers, manufacturers, third-party logistics providers, retailers, and customer tiers. A mixed-integer non-linear programming (MINLP) model is developed to minimize the overall anticipated cost that consists of costs related to procurement, production, inventory holding, shortages, material for return units, recycling, repairing, disposal, and transportation cost, across the entire supply chain network. The problem under consideration is NP-hard in nature. The special challenges of the problem in consideration are to consider all pickup and distribution nodes of retailers/customers within the range of promising time horizons. For solution purposes, the Block-based Genetic Algorithm, Fruit-fly Algorithm, and CPLEX are used. Computational experiments show the comparative charts and trends that are put on to an extensive range of practical scenarios. The experiments reveal that the Genetic Algorithm

performs well than the Fruit Fly algorithm in terms of rate of convergence and solution quality in all cases of interest. CPLEX solution provides the minimum optimal value.

Keywords: forward logistics, logistics, meta-heuristics, multi-modal transportation, industry 4.0, refurbished products, reverse logistics, supply chain network design, sustainability

1. INTRODUCTION

The research domains of sustainable logistics network design have been trending for the last decade. Supply chain members have now realized the benefits of working towards the benefits of the entire supply chain rather than focusing on their profits alone (Daultani *et al.*, 2015). This has resulted in an increasing need for coordinated efforts toward designing optimal forward and reverse distribution networks. The rise of e-commerce firms and tremendous customer response have also increased complexities for logistics service providers (LSPs). Returns or defective products have to be transported from customers to manufacturers. To reduce waste, manufacturers repair and recycle defective/used products and sell them as refurbished products. Increasingly, refurbished products are being sold in business-to-consumer markets at discounted prices to attract customers (Harms & Linton, 2016). Therefore, now LSPs have to fulfill both the new and refurbished product

demand of the retailers. The security of the supply chain and anthropogenic emissions are high on the global research agenda. Rao (2010) indicated that the transportation network is a major contributor to 23% of carbon dioxide emissions and estimated a three to fivefold rise of anthropogenic emissions from the logistics network worldwide by 2030. The existing investment strategies and policies need to be modified for reducing the negative environmental impact. This is driven by the anticipated six to eight-fold growth in a large increase in the number of trucks and the number of light-duty vehicles, which could overcome even the utmost optimistic predictions of improvements in the fuel efficiency of the transport vehicle. Schipper *et al.* (2009) described that the growth of Gross Domestic Product (GDP) per capita in developing countries also depends on the mobility of cargo and products from the source to the destination. Gradually, LSPs are increasing the number of light vehicles and heavy vehicle trucks to fulfill the customer demand within the promised time, resulting in increased emissions of anthropogenic gases into the environment.

In current years, the importance of protecting the environment and saving natural resources through recycling and safe disposal has withdrawn the attention towards reverse logistics (Atabaki *et al.*, 2019). The number of product returns through e-commerce platforms is sharply rising because of emotional consumption, profit-driven consumer, defects in products, and information asymmetry (Zhang *et al.*, 2020). Further, due to governments' rules and regulations related to environmental concerns, manufacturers have now realized the importance of implementing an environmentally friendly supply chain (Kannan *et al.*, 2012). However, there are several challenges to implementing and integrating sustainability and Industry 4.0 aspects in supply chains (see, Goswami *et al.*, 2020 and Goswami & Daultani, 2021 for more details). Specifically, the relevant gaps are regarding the proper application of sustainability in the logistics and supply chain. Along these lines, this paper proposes an optimization model that implements outstanding business intellect while catering to the necessities of adoption of sustainability, people, environment, and prosperity in the logistics and supply chain.

In the Worldwide competition, the transportation system requires extra attention to rise the financial performance of e-commerce enterprises. The manufacturing companies produce and supply manufactured products to warehouses by several ways of transportation. An e-commerce platform has information related to the availability of products, cost, distance from the warehouse, etc. at the suppliers and location of the customers. The buyers place the orders by using E-commerce, and suppliers transport the products to the buyers within the promised time window. However, sometimes, consumers receive defective/damaged and unsatisfactory items. As per the return policies, the consumers can return the defective/damaged and unsatisfactory items within some pre-specified time. Due to the lack of information synchronization in the system, the e-commerce platform allocates the third-party logistics service provider to collect the returned product from the consumer resulting in additional transportation costs and increasing carbon

emissions. In general, suppliers and customers are not connected directly. Their information lies with the e-commerce firm, and suppliers supply the finished items directly to the warehouse of the e-commerce firm. Due to the lack of information sharing, more than the optimal trucking capacity is used for transportation. This results in higher transportation costs and supply chain inefficiencies across the network. To cater to the above-mentioned issues, the truck allocation should be based on order capacities, and the shortest route within the supply chain network to lessen the total travel distance. To address these complex challenges, this paper focuses on designing the optimal forward and reverse supply chain network for new and refurbished products in the context of e-commerce logistics.

The rest of the paper is organized as follows. Section 2 presents a detailed literature review. Problem formulation is showcased in Section 3. Next, section 4 explains the proposed solution method. Section 5 has results and a discussion. Section 6 offerings the conclusions and future research directions.

2. LITERATURE REVIEW

The literature review has been classified based on forward supply chain network design and reverse supply chain for the scrap/defective items and forward-reverse supply chain network in an integrated manner.

Some of the researchers focussed on the logistics network design and minimized the transport time and cost. Serrano *et al.* (2013) described the green logistics network design and developed a mixed-integer linear programming (MINLP) model to capture the reverse logistics network design. A hybrid priority-based genetic algorithm introduced by Gen *et al.* (2018) dealt with a problem related to the sugarcane supply chain logistics network design network as a location-allocation capacity model. Govindan *et al.* (2017) described the uncertainties in supply chain network design and proposed fuzzy mathematical modeling to capture recourse-based, risk-averse stochastic programming. Zhang *et al.* (2017) addressed a less-than-truckload problem for forward logistics and developed a model to analyze the e-commerce scenario. They have formulated an e-commerce model and maximized the total profit without affecting the individual revenue of logistics carriers. Nagpal *et al.* (2021) performed a deep analysis of the published articles in the field of demand substitution and they found most of the articles are related to profit maximization by minimizing the cost with optimization.

Ramezani *et al.* (2013) proposed a stochastic model for multi-objective forward and reverse logistics problems and attempted to arrest the three-echelon supply chain (in the forward direction there are suppliers, plants, and distribution centers) and two-echelons in the backward direction, collection centers, and disposal centers). Afia (2010) introduced a multi-echelon multi-period FRLND in the risk model, and the proposed logistics network involves three echelons in forward logistics and two-echelon in reverse logistics. For green FRLND, Zerbakhshnia *et al.* (2018) developed a novel multi-objective mixed-integer linear programming model, which minimizes the cost of processes and operations, fixed cost for the establishment, and

transportation cost. Zhang *et al.* (2019) proposed a game-theoretic approach to horizontal carrier coordination during the forward logistics design and determined optimal revenue. Zhang *et al.* (2020) addressed VRP along with order pickup and delivery from multiple nodes simultaneously with time windows in business-to-consumer e-commerce forward and reverse logistics systems. Bargaining and consumer returns in the context of a closed-loop supply chain were investigated by (Tanai *et al.*, 2021). In the case of heterogeneous products, Cantillo *et al.* (2021) have proposed a two-phase strategy. However, their context was more on the loading and delivery of the trucks. Similarly, the nuances related to the backtracking restrictions were attempted by (Bowden and Ragsdale 2020) in the case of a general context.

Choudhary *et al.* (2015), incorporated the carbon emission-related parameters along with the various decision variables to minimize the transportation cost as well as carbon footprint. They revised the conventional integrated model of FRLND into the model of quantitative operational decision-making. Guo *et al.* (2017) focused on the FRLND and planning for the route with considering the minimum carbon emission. They aimed to lessen the total system cost along with the least cost related to circulation-type delivery routing with the reduction in carbon emissions. Gooran *et al.* (2020) advocated for reusing the returned products as an apt response to the concerns related to environmental sustainability. Prajapati *et al.* (2021a), investigated integrated transportation and VRP along with environmental and economical sustainability in a B2B e-commerce logistics system. However, Prajapati *et al.*, (2021b) considered the social sustainability factor that is the driver safety concern in a VRP for the delivery of products in a very short time window in a B2B e-commerce platform. Hardjomidjojo *et al.* (2022) introduced a fresh approach to determine the minimum supply and imbalance demands in sustainable agro-industry logistics networks by applying spatial analysis. The supply chain operations reference is used by Islam *et al.* (2022) for the selection of the main operational steps of the SCM and metering criteria for the fish farmers. Handaya *et al.* (2022) implemented the soft system dynamic methodology (SSDM) in the palm kernel shell supply chain, which is a waste of palm oil processing. They demonstrated how to use SSDM for the design and analysis of the network of supply chains with sustainability with the help of mathematical modeling and simulations. Sahu and Rao (2021) created a theoretical model and make a novel scale for examining the factors that obstruct the implementation of SCM in India. Prajapati *et al.* (2022) focused to develop a logistics network that includes first-mile pickup and last-mile distribution of agro-food grains along with the triple bottom line of sustainability. They have considered the food damage and driver safety concerns caused by accidents. Taking this work further, Singh *et al.* (2022) investigated the barriers to growth in the Indian food processing sector.

McWilliams *et al.* (2022) tried to answer the fundamental questions associated with the risk perception and risk attitude of SCM professionals in the assessment and assortment of suppliers. They have used three steps of methodologies as a sample, measures, and common method variance for the factorial analysis of the empirical data. Sharma and Singla (2021) focused to introduce a mid-way

approach to the implementation of sustainability in supply chain practices by a firm while dealing with its organizational performance and functional constructs. Dwivedi *et al.* (2020) proposed a sustainable supply chain network design for agro-food grains and formulated an MINLP model to optimize the total cost associated with the proposed network. For the solution purpose, they used exact optimization in LINGO 18 optimization solver and metaheuristics, which are the GA and quantum-based GA.

From the literature, it can be concluded that very few researchers have focussed on forward and reverse supply chain network design as an integrated problem. Due to the lack of information synchronization, an e-commerce Company must only pick up activity from the customers at a time or deliver products directly to the customer at another time. There will be a loss in transportation costs causing increased carbon emissions. Daultani *et al.* (2019) considered a few of the above-mentioned issues in their conference paper, and they were able to solve only small instances with CPLEX. The current work is an extension of their paper in the sense that the network model is more evolved and complex with additional constraints and is solved through two metaheuristics with additional experimentation. This paper addresses the research gap to synchronize the information in the supply chain network, develop a network for pickup-delivery routes simultaneously, and reduce the transportation costs associated with carbon emissions.

3. PROBLEM FORMULATION

3.1 Problem Description

The governments of developing countries are focusing to reduce carbon emissions in their transportation sector and have imposed carbon reduction policies on the manufacturers and logistics service provider companies. Such companies need to design and develop the forward and reverse supply chain network with minimal carbon emission, as proposed in **Figure 1**. In this figure, there are eight major entities such as manufacturing center, storage, retailer warehouse, distribution center, disassembly center, recycling center, disposal center, and customers. The manufacturing center produces the finished products and sends them to the retailer's warehouse and self-storage units to maintain the inventory. Retailer warehouses buy the finished products from the manufacturing center and then sell them to the end users from their inventory. Storage center store the extra units produced as safety stock. The distribution center distributes the finished products to the customers. The disassembly center collects the returned products from customers and categorized them into two recyclable and disposable products. Recyclable products move from the disassembly center to the recycling center and are recycled at the recycling center and further move towards the manufacturing center for remanufacturing. Disposable products get disposed of at the disposal center. Suppose there are any faulty items available to retailers, which has been returned by the consumers, the logistics service provider picks up the faulty/scrap item and transports them to the respective manufacturing firms.

The challenge of the proposed logistics network is to keep all pickup and delivery nodes of retailers/customers

within the promising range of time horizon while simultaneously minimizing the effect of the greenhouse effect from various transportation services. The assumptions taken in the model are enlisted below. Further, the next

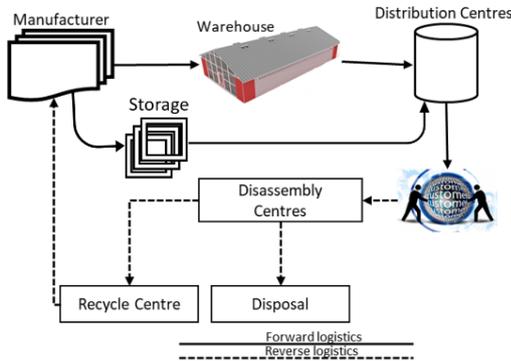


Figure 1. Forward-reverse Logistics Network between Manufacturer and Retailers

3.1.1 Assumptions

- i. Multi-period and multi-echelon supply chain structure is considered.
- ii. Facility layout costs for each time period are fixed.
- iii. Each location has a finite capacity for different products.
- iv. Product holding costs depend upon the remaining inventory level.
- v. The distance between the disposal center and the disassembly location is negligible.
- vi. Customer demand sets are known.

3.2 Mathematical Model

3.2.1 Index

- m Set of manufacturers ($m=1,2,\dots,M$)
- w Set of warehouse centres ($w=1,2,\dots,W$)
- s^{\sim} Set of storage centres ($s^{\sim}=1, 2,\dots,S^{\sim}$)
- r^{\sim} Set of recycling centres ($r^{\sim}=1, 2,\dots,R^{\sim}$)
- t Set of time periods ($t=1,2,\dots,T$)
- c Set of distribution centres ($c=1,2,\dots,C$)
- d Set of disassembly centres ($d=1,2,\dots,D$)

3.2.2 Parameters

- C_M The raw material cost per unit quantity supplied by the manufacturer
- C_p Production cost per unit product
- C_r Recycling cost of product per unit recycled
- H_c Fixed holding cost per unit product
- C_p^l The cost of purchasing recycling (per unit)
- $F_{i,j}$ Transportation cost to supply the products from the node i to node j (location)

3.2.3 Decision Variables

- $Q_{t,m,w}$ The products movement from node m to node w in period time t
- $Q_{t,w,c}$ The products movement from node w to node c in period time t
- $I_{s^{\sim},c,t}$ The products supply from node s^{\sim} to node c in period time t

section presents the proposed mathematical model that captures the intricacies of the proposed FRLND as proposed in **Figure 1**.

- $Q_{d,w,t}$ The number of products moving from node d to node w in period time t
- $Q_{u,d,t}$ The products shipped from node u (first user) to node d in period 't'
- $Q_{r^{\sim},w,t}$ The products shipped from node r^{\sim} to node w in period time t
- $Q_{rd,d,r^{\sim},t}$ The amount of products transfer from node d to node r^{\sim} in period time t
- $R_{s^{\sim},t}$ Inventory remaining at node s^{\sim}
- $R_{c,t}$ Inventory remaining at node c

$$y_{ij} = \begin{cases} 1, & \text{if the products movement occurs} \\ & \text{between manufacturer } i \text{ to location } j \\ 0, & \text{otherwise} \end{cases}$$

3.2.4 The Objective function and Constraints

The objective function describes the total costs associated with total material cost (Z1), production cost (Z2), material cost (for return units, Z3), shortage cost (Z4), purchasing cost (Z5), recycling cost (Z6), inventory holding cost at storage and distribution centers (Z7), repairing cost of unsatisfactory products (Z8), disposal cost (Z9) and shipping cost from i to j depot (Z10).

$$Z1 = \sum_t^T \sum_{m=1}^M \sum_{w=1}^W Q_{t,m,w} C_M$$

$$Z2 = \sum_{t=1}^T \sum_{w=1}^W \sum_{c=1}^C Q_{t,w,c} C_p$$

$$Z3 = \sum_{s^{\sim}=1}^{\tilde{S}} \sum_{c=1}^C \sum_{t=1}^T I_{s^{\sim},c,t} C_p$$

$$Z4 = \sum_{d=1}^D \sum_{w=1}^W \sum_{t=1}^T Q_{d,w,t} (C_R - C_M)$$

$$Z5 = \sum_{u=1}^U \sum_{d=1}^D \sum_{t=1}^T Q_{u,d,t} C_p^l$$

$$Z6 = \sum_{r^{\sim}=1}^{R^{\sim}} \sum_{w=1}^W \sum_{t=1}^T Q_{r^{\sim},w,t} (C_R)$$

$$Z7 = H_c \left[\sum_{s^{\sim}=1}^{\tilde{S}} \sum_{t=1}^T R_{s^{\sim},t} + \sum_{d=1}^D \sum_{t=1}^T R_{c,t} \right]$$

$$Z8 = \sum_{d=1}^D \sum_{r^{\sim}=1}^{R^{\sim}} \sum_{t=1}^T Q_{rd,d,r^{\sim},t} C_{rep}$$

$$Z9 = \sum_{d=1}^D \sum_{g=1}^G \sum_{t=1}^T Q_{d,g,t} C_{dis}$$

$$Z10 = \sum_{i=1}^I \sum_{j=1}^J P_{i,j} \cdot y_{i,j}$$

Objective Function

$$\text{Min } Z = Z1 + Z2 + Z3 + Z4 + Z5 + Z6 + Z7 + Z8 + Z9 + Z10 \quad (1)$$

Constraints

$$\sum_{i=1}^{T_1+M} y_{i,j} = 1, \forall j \in (1, 2, \dots, M) \quad (2)$$

$$\sum_{j=1, j \neq i}^{T_1+M} y_{i,j} = 1, \forall i \in (1, 2, \dots, T_1) \quad (3)$$

$$\sum_{i=1, i \neq j}^{M+W} y_{i,j} = 1, \forall j \in (1, 2, \dots, W) \quad (4)$$

$$\sum_{j=1, j \neq i}^{M+W} y_{i,j} = 1, \forall i \in (1, 2, \dots, M) \quad (5)$$

$$\sum_{i=1, i \neq j}^{\tilde{W}+C} y_{i,j} = 1, \forall j \in (1, 2, \dots, C) \quad (6)$$

$$\sum_{j=1, j \neq i}^{\tilde{W}+C} y_{i,j} = 1, \forall i \in (1, 2, \dots, \tilde{W}) \quad (7)$$

$$\sum_{i=1, i \neq j}^{C+U} y_{i,j} = 1, \forall j \in (1, 2, \dots, U) \quad (8)$$

$$\sum_{j=1, j \neq i}^{C+U} y_{i,j} = 1, \forall i \in (1, 2, \dots, C) \quad (9)$$

$$\sum_{i=1, i \neq j}^{D+L} y_{i,j} = 1, \forall j \in (1, 2, \dots, L) \quad (10)$$

$$\sum_{j=1, j \neq i}^{D+L} y_{i,j} = 1, \forall i \in (1, 2, \dots, D) \quad (11)$$

$$\sum_{i=1, i \neq j}^{L+R_1} y_{i,j} = 1, \forall j \in (1, 2, \dots, R_1) \quad (12)$$

$$\sum_{j=1, j \neq i}^{L+R_1} y_{i,j} = 1, \forall i \in (1, 2, \dots, L) \quad (13)$$

$$\sum_{i=1, i \neq j}^{R_1+F} y_{i,j} = 1, \forall j \in (1, 2, \dots, F) \quad (14)$$

$$\sum_{j=1, j \neq i}^{R_1+F} y_{i,j} = 1, \forall i \in (1, 2, \dots, R_1) \quad (15)$$

$$\sum_{s=1}^S \sum_{f=1}^F Q_{t,m,f} = \sum_{f=1}^F \sum_{d=1}^D Q_{f,d,t} + \sum_{f=1}^F \sum_{f^*=1}^{F^*} I_{f,f^*}, \forall t \in \{1, 2, \dots, T\} \quad (16)$$

$$\sum_{l=1}^L Q_{c,l,t} \leq \left(\sum_{d=1}^D Q_{d,c,t} \right) R_r, \forall t \in (1, 2, \dots, T), \forall c \in (1, 2, \dots, C) \quad (17)$$

Equation (1) defined the objective function. The constraints (2-3) ensure that the transportation of products occurs between depots i to manufacturer depot j . Constraint (4-5) describes that the product flows between suppliers to warehouse centers. The products move from storage centers to distribution centers described in constraint (6-7). The constraints (8-9) ensure that the product will reach to destination (customers) through distribution centers. The constraint (10-11) defines the transportation path between consumers' locations to the disassembly location. The transportation network exists between the Disassembly to recycling centers and recycling to manufacturer describes in constraints (12-13) and constraint (14-15) respectively.

Constraint 16 enforces that the total quantity of products transports from manufacturers to warehouse and recycled products are equal to the total quantity of products that flows from warehouse to distribution centers. Constraint 17 ensures that the total number of products that flows from the customer to disassembly centers does not more than the sum of total products entered into the customer zone through distribution centers.

4. SOLUTION APPROACH

The proposed study deals with the FRLND for new and refurbished products. A mathematical model is formulated by using mixed-integer non-linear programming (MINLP) approach, and the problem is broadly categorized as a VRP, which is an NP-hard problem (Patidar *et al.*, 2018). As proposed by Mohammadi *et al.* (2020), algorithms like genetic algorithms can be used in this case. Therefore, two meta-heuristics (i.e., fruit fly algorithms and block-based genetic algorithm) are used for the solution and to determine the total revenue generated by the system. Also, the results are compared with the results obtained from ILOG CPLEX.

4.1 Fruit fly Algorithm

The fruit fly algorithm is a search-based nature-inspired algorithm proposed by Wen Tsao Pan (2011). It is based on fruit fly search techniques for food through smell and efficient vision strengths. They can smell up to 40 km far away from the food. There are two phases in which fruit fly searches the food zone through smell and then reach the food destination zone through vision. The remaining algorithm steps are described in the following steps:

Step 1: Tune the parameters

Step 2: Position the fruit fly randomly

Step 3: Search the food source flying randomly by using Eq.A

$$X_i = X_{coordinate} + randomnumber$$

$$Y_i = Y_{coordinate} + randomnumber$$

Step 4: For every fruit fly, determine the smell concentration (as shown in equation B)

$$distance_i = \sqrt{X_i^2 + Y_i^2}$$

$$S_i = \frac{1}{distance_i}, Smell_i = Func(S_i)$$

Step 5: Evaluate the best fly location, on the basis of smell concentration and swarm location for next iterations (in equation C)

$$[bestSmellbestindex] = maximum(smell)$$

$$X_{coordinate} = X(bestIndex)$$

$$Y_{coordinate} = Y(bestIndex)$$

Step 6: If stopping criteria satisfied and obtained best near optimal solution, otherwise returned back to step 3.

4.2 Genetic Algorithm

To determine the objective value, we have used a genetic algorithm (Deb & Goel, 2001; Pratap *et al.*, 2016), which is a stochastic approach. The genetic algorithm is the search-based approach to solving allocation and scheduling problems.

4.2.1 Chromosome Generation

The genotype of GA generates the random solution of blocks and checks the feasibility, and whether the fitness function is obtained. In this problem, we have built the chromosome based on retailers. The binary-encoded GA represents that if the retailer is getting orders, it will be 1 or either 0 (as shown in **Figure 2**).

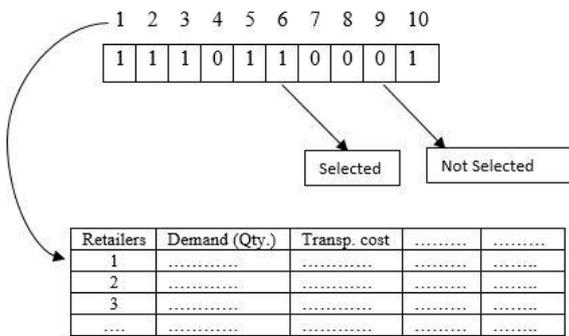


Figure 2. The Formation of (Parent) Chromosome

4.2.2 Crossover Operation

The parent chromosome performs crossover and generates the two new child chromosomes. In this, we have used a single-point chromosome of binary-coded blocks (as shown in **Figure 3**).

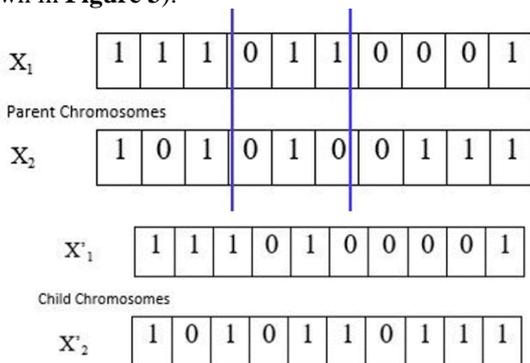


Figure 3. Crossover Operation

4.2.3 Mutation Operations

The mutation operation performs on the best child chromosome, and the flip mutation block will be interchanged for the binary-coded genotypes, represented in **Figure 4**.

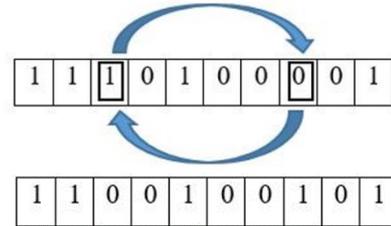


Figure 4. Mutation Operation

If the final child chromosomes satisfy the fitness function (objective function), then the final solution is obtained. Either, it will again go for chromosome crossover operations. The flowchart described the process of the Genetic Algorithm in **Figure 5**.

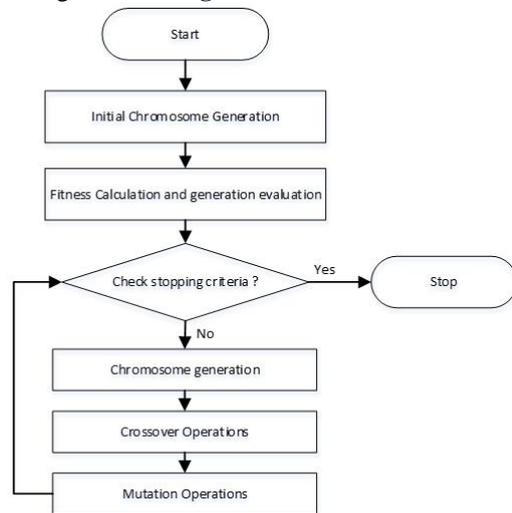


Figure 5. Flowchart of Genetic Algorithm

5. RESULTS AND DISCUSSIONS

In this paper, we have used the simulated dataset and tested the model on ten instances. We used the software MATLAB 2016(a) on an i5 processor (8.0 GHz) on Windows 10 platform and determined the solution through Fruit fly Algorithm and Genetic Algorithm. **Figure 6** and **Figure 7** show the convergence graph of the Fruit fly algorithm and Genetic Algorithm for the first 2 instances.

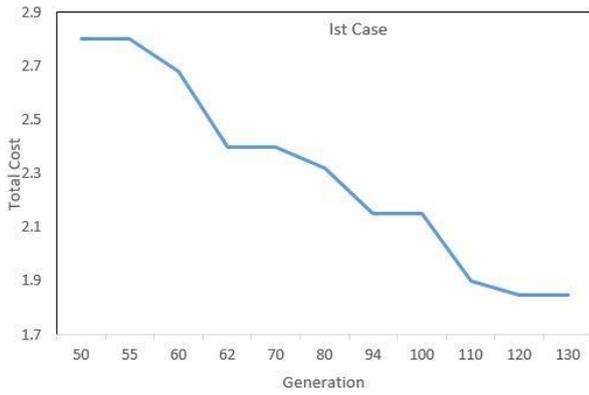


Figure 6 (a): Convergence Graph of Fruit Fly Algorithm (I Instance)

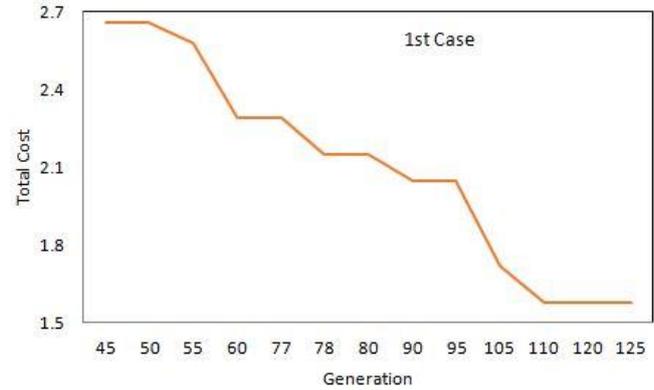


Figure 6 (b): Convergence Graph of Genetic Algorithm (I Instance)

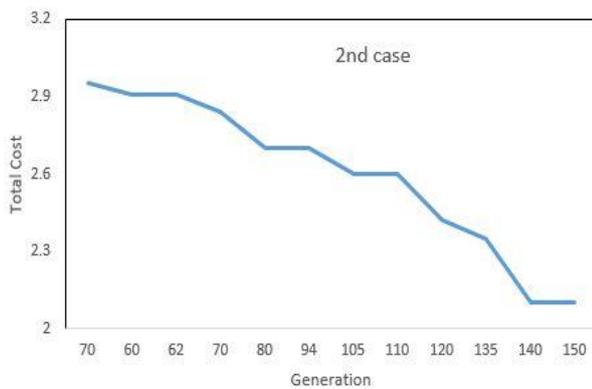


Figure 7 (a): Convergence Graph of Fruit Fly Algorithm (II Instance)

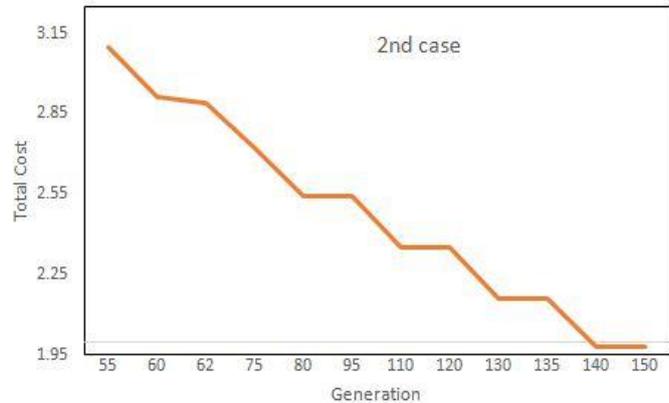


Figure 7 (b): Convergence Graph of Genetic Algorithm (II Instance)

5.1 Convergence Graph

The computation experiment reveals that in all the considered cases, the Genetic Algorithm performed better than the Fruit Fly algorithm in terms of the rate of convergence and quality of the obtained solution. We have conducted the tests on ten instances as described in **Table I**. From **Table I**, we can observe that the optimal value of the overall cost is minimum from ILOG CPLEX as compared to the metaheuristics while the genetic algorithm takes minimum computation time. For small-sized data sets, the difference in objective function value as well as in computational time for the three different solutions is a very close relative. However, in large-sized data sets, it becomes

more as we can see in the last three instances of computational results **Table 1**. The exact optimization approach i.e., ILOG CPLEX performed better in the case of the optimized minimum value of total cost than the metaheuristic approaches i.e., Fruit Fly algorithm and genetic algorithm. Whenever case computational time for large-sized problems the metaheuristics performed better.

Figure 8, shows the optimized network of forward and reverse logistics for the first case instance. The value of decision variables like quantity moving from one node to another is depicted in **Figure 8**. For example, the quantity moving from manufacturing center- 1 to warehouse 2 is 142, the quantity moving from storage center 1 to distribution center 2 is 50, and so on.

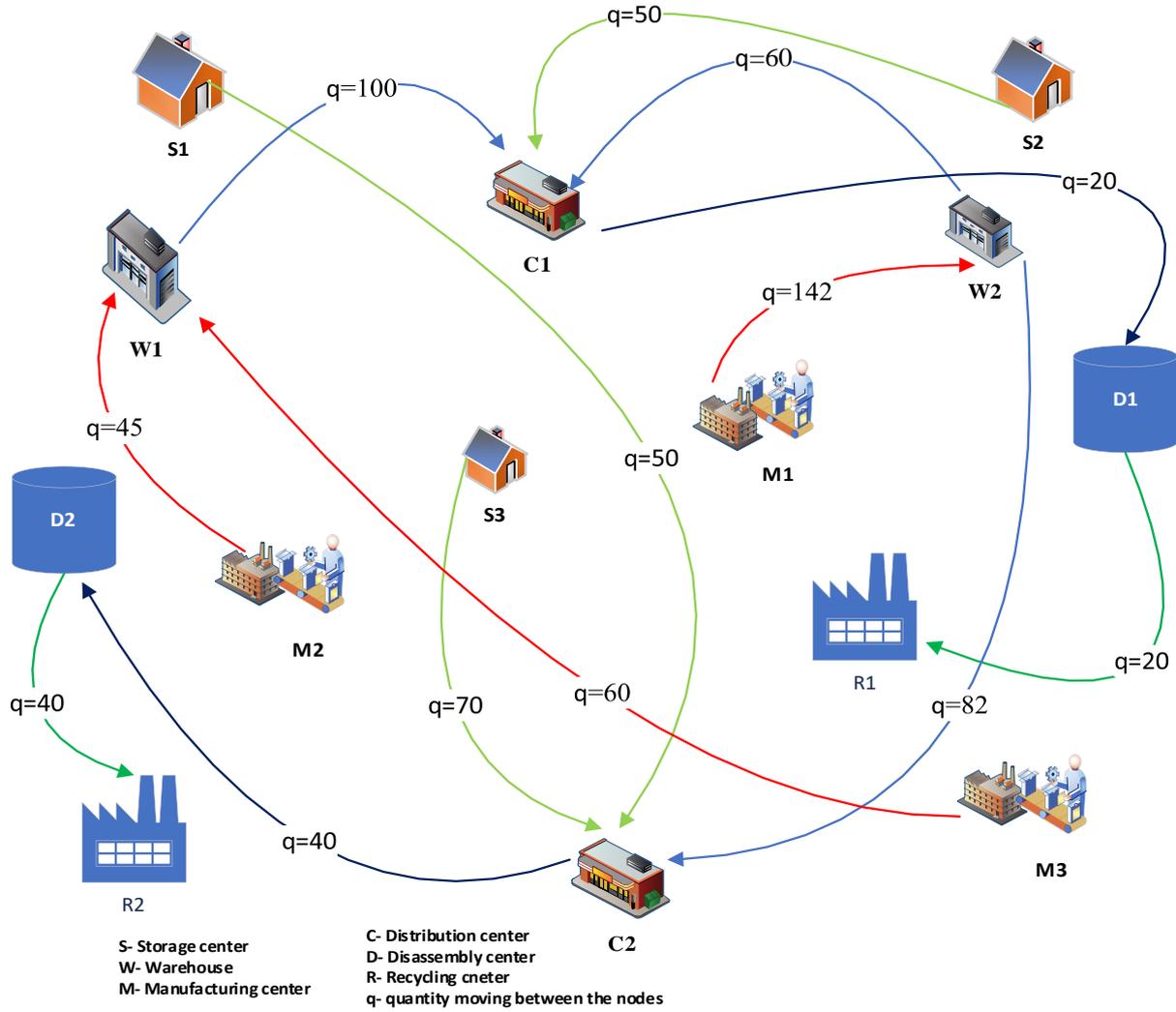


Figure 8. Optimized Network of Forward and Reverse Logistics for First Instance

Table 1. Computation Results

Instances (<i>m,w,c,d</i>)	Variables	Constraints	Fruit Fly Algorithm		Genetic Algorithm		ILOG CPLEX	
			Objective function (Million \$)	Computation Time (Seconds)	Objective function (Million \$)	Computation Time (Seconds)	Objective function (Million \$)	Computation Time (Seconds)
I (3,2,1,2)	4513	2689	1.98	69	1.92	65	1.85	69
II (3,3,2,2)	5362	2891	2.27	74	2.24	72	2.10	76
III (4,3,1,2)	6844	3189	3.73	81	3.71	79	3.52	81
IV (4,4,2,3)	8938	5438	4.41	85	4.39	80	4.23	89
V (5,4,2,4)	10965	7954	5.97	101	5.92	98	5.81	102
VI (6,5,3,4)	16684	9185	7.28	106	7.12	105	6.90	113
VII (6,5,4,4)	21646	10167	7.42	121	7.37	116	7.25	129
VIII (8,7,6,7)	29756	16580	11.56	153	11.35	142	10.98	260
IX (10,9,12,11)	41875	28380	25.26	189	25.01	168	24.56	598
X (12,15,18,17)	48255	31884	41.56	241	41.13	225	39.89	879

Table 2. Comparative Percentage Change in Metaheuristics with ILOG CPLEX

Instances (<i>m,w,c,d</i>)	Fruit Fly Algorithm		Genetic Algorithm	
	% of Objective Function above than ILOG CPLEX	% of Computation Time (Seconds) below than ILOG CPLEX	% of Objective Function above than ILOG CPLEX	Computation Time (Seconds) below than ILOG CPLEX
I (3,2,1,2)	7.02%	0%	3.78%	5.79%
II (3,3,2,2)	8.09%	2.63%	6.66%	5.26%
III (4,3,1,2)	5.97%	0%	3.71%	2.47%
IV (4,4,2,3)	4.26%	4.49%	3.78%	10.11%
V (5,4,2,4)	2.75%	0.89%	1.89%	3.92%
VI (6,5,3,4)	5.51%	6.19%	3.19%	7.08%
VII (6,5,4,4)	2.34%	6.20%	1.66%	10.08%
VIII (8,7,6,7)	5.28%	41.15%	3.37%	45.38%
IX (10,9,12,11)	2.85%	68.39%	1.83%	71.91%
X (12,15,18,17)	4.19%	72.58%	3.11%	74.40%

From **Table 2**, we can see more value of the objective function obtained from metaheuristics with the base of ILOG CPLEX percentage-wise, and also for less computational time. For large-sized data sets, the percentage of computation time is higher.

This study mainly focused on the minimization of the total cost of forward and reverse supply chain network (FRSCN) by optimizing the pickup-delivery routes, resources, and processes (like recycling repairing, production, etc.) facilities within the network. Also, by finding the optimum number of transport quantities to be shipped through optimized value of assigned vehicles required, with the help of the proposed MINLP optimization model. This model includes ten different costs such as total material cost, production cost, material cost (for return units), shortage cost, purchasing cost, recycling cost, inventory holding cost at storage, and distribution centers, repairing cost of unsatisfactory products, disposal cost and shipping cost from *i* to *j* depot. The optimized value of the total cost of the forward and reverse supply chain for the ten different case scenarios are written in **Table 1**. The obtained results and analysis could help government and business organizations to create some policies in favor of environmental aspects of sustainability and development of business and nation.

6. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

This paper captures major complexities associated with the FRLND from the manufacturer to the customer and vice-versa. The studied model is mathematically formulated as a mixed-integer non-linear programming (MINLP) model that considers the total anticipated costs related to production, recycling, transportation, inventory, and shortage during forward-reverse movements of goods in the network, disposal, and recycled. The two meta-heuristic algorithms, namely the Fruit fly algorithm and block-based Genetic Algorithm, and ILOG CPLEX have been used to optimize the total anticipated cost. The proposed model in this study has been tested on several case scenarios and observed that the outcomes of the CPLEX are better than the Genetic

Algorithm and Fruit Fly Algorithm in case of the minimum optimized value of the total cost. However, in case of near optimal solution, metaheuristics perform better than the global optimal approach i.e., ILOG CPLEX. In the future, this model could be extended for new and refurbished products with socio-sustainable and Industry 4.0 factors.

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